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PATENT

**A PERIODIC INTERLEAVED STAR WITH VIAS ELECTROMAGNETIC
BANDGAP STRUCTURE FOR MICROSTRIP AND FLIP CHIP
ON BOARD APPLICATIONS**

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5 **A Periodic Interleaved Star with Vias Electromagnetic
 Bandgap Structure for Microstrip and Flip Chip
 On Board Applications**

Background of the Invention

10 This application is a continuation in part of parent application titled "Improved
Flip Chip MMIC on Board Performance Using Periodic Electromagnetic Bandgap
Structures" filed2004, serial number

15 Field of invention

 This invention is in the field of cross - talk suppression in a hybrid assembly at
microwave frequencies.

20 Description of the Related Art

 Monolithic Integrated Circuits (MMIC), an example of a semiconductor struc-
ture, support many of the present generation of military and commercial radio fre-
25 quency sensors and communication applications. MMICs include active devices, such
as field effect transistors and bipolar transistors, passive elements such as capaci-
tors, thin film / bulk resistors, and inductors integrated on a single semi-insulating
substrate, such as Gallium Arsenide.

30 Hybrid technology relates to methods used for interconnecting a plurality of
separate semiconductor structures, such as MMICs, to a host substrate, in single,
or multi-layer configurations. In a hybrid, inter-connections between the semicon-
ductor structures is sometimes along the surface of the host substrate. These inter-
connections are frequently made using metallized paths connected to bumps (soft
35 solder, or hard plated bumps). These bumps, located on the surface of the substrate,
engage conductive pads on the semiconductor structures thus forming conductive,
interconnecting paths between the host substrate and the semiconductor structures.

5 The bumps are used as a substitute in place of wire bonds for connections. The advantage of bumps over wire bonds include the elimination of wafer backside processing steps such as wafer thinning, via formation, and metal deposition.

Another advantage to using surface bumps for interconnection purposes is the
10 lower thermal resistance between the semiconductor structures and the host substrate. The lower thermal resistance of the bump connection is due to the relatively large surface area of contact between the host substrate and the semiconductor structures. Heat transfer is also facilitated by the large diameter and short length of the bump, as compared to a wire interconnect. Although both the bump and the wire are made
15 of thermally conductive metal, the favorable aspect ratio of the bump and wider surface area present a lower thermal resistance as compared to a typically thin, long wire bond. The lower thermal path presented by the bump facilitates the conduction of heat away from the semiconductor structures, allowing higher power density for the semiconductor/substrate hybrid assembly, especially when using thermal bumps
20 directly under heat sources. The higher power density allows higher performance for the hybrid.

Yet another advantage of using bumps for interconnect purposes is the elimination of parasitic effects such as capacitance, inductance and radio emissions present
25 with wire bonds and vias. At high frequencies, the thin, long wire bonds, and the vias traversing the thickness of the substrate can be considered as antennas for the emission of electromagnetic interference. The same wires and vias present capacitance to adjacent structures, as well as an inductance to the signals transmitted by the wires.

30 Other advantages of bumps are their lower cost and higher reliability. Typically bump type connections can be efficiently completed using a single epoxy cure/solder reflow die-attach process. This presents fewer steps during manufacture as compared to wire bond techniques. With bump interconnect, there are no mechanical wire connections to shake loose, be intermittent or fail due to thermal cycling.

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While bumps are advantageous as compared to wire inter-connections, their presence between a semiconductor structure and a host substrate presents unique

5 electromagnetic resonance and emission packaging problems. First, there is the optimization of the vertical radio frequency interconnect transitions presented by the interface between the bumps on the host substrate and the semiconductor structure mounted thereon. Then there is the potential electromagnetic coupling effects presented at the interface between the semiconductor structure and the host substrate,
10 as well as the host substrate opposing surfaces.

A particular difficulty introduced by the semiconductor structure mounted on the host substrate is the potential formation of electromagnetic boundaries which support unwanted, parallel plate, waveguide like (surface modes) of energy propagation.
15 Such unwanted modes can propagate near the surface of the host substrate causing degradation in semiconductor performance because of signal interference. The degradation in semiconductor performance are caused by unwanted signal transfer among semiconductor structure inputs and outputs, affecting gain and phase response, loss of isolation between adjacent paths in multiple path / multiple channel circuit applications, and circuit instability. These negative effects are due to the introduction of
20 unwanted coupling or feedback paths.

Maximum frequency operation of the semiconductor in the presence of these unwanted feedback paths are undesirably dependent on the dimensions of the semiconductor structure. Thus, semiconductor structures with large dimensions with respect to wavelength operating frequency present a potential difficulty. This difficulty is prevalent with fast Gallium Arsenide (GaAs) semiconductor structures mounted on a host substrate. The relatively large semiconductor size of GaAs as compared to the wavelength of the operating frequency approach the cutoff frequencies at the
30 upper edge of the operational band. Near cutoff, the semiconductor structure may be functional, but unable to operate because the incoming signals are interfering with each other.

In the prior art, signal interference is reduced by incorporating grounded interconnect bumps strategically placed on the semiconductor structure surface to break
35 up surface modes of energy propagation. By making direct contact to ground pads on the host substrate, the path of the surface modes is disrupted. These grounded

5 interconnect bumps act like shields and attempt to change the path to be followed by
the electromagnetic energy propagated along the surface of the host substrate. Unfor-
tunately, because of semiconductor structure limitations and assembly requirements,
this practice of using redundant ground bumps as obstacles to surface propagated
electromagnetic waves results in a further increase in both semiconductor structure
10 and substrate size, increasing weight, power consumption and reducing reliability of
the resulting hybrid.

Another approach described in the parent application to reduce surface modes
is to tessellate the area of the substrate located in the proximity of the semiconductor
15 structures with multiple layers of EBG regular polygons. The limitation here is that
a plurality of of EBG layers may have to be used to achieve the level of attenuation
desired. The plurality of EBG layers, as compared to a single EBG layer, reduce
reliability and increase cost of the hybrid.

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Summary of the invention

Above limitations are improved by a hybrid assembly comprising a single elec-
tromagnetic band gap (EBG) layer on a substrate having an upper surface and a
25 lower surface and a semiconductor structure (MMIC) mounted above the EBG layer.
The hybrid operates typically at microwave operating frequencies. Conductive paths
are etched on the upper surface for conducting high frequency signals along the upper
surface of the substrate.

30 A plurality of stars made of an EBG material, forming the EBG layer, are
preferably printed, or deposited, on the upper surface. The EBG material has slow
wave characteristics. The plurality of stars tessellates the upper surface between the
conductive paths, generally in an area below the semiconductor structures.

35 Each of the stars has a center section formed from a regular polygon, the center
section having projections extending from the center section. The projections and
the center section form a periphery. The periphery engages adjacent stars along the

5 periphery. Stars are separated from adjacent stars by an interspace. The interspace is preferably constant along the periphery. Stars are also separated by a distance from the conductive paths. Each of the stars is connected to a conductive via, in turn connected to ground potential. In one embodiment, the lower surface is covered with a conductive layer at ground potential. This conductive layer is electrically
10 continuous with vias used to interconnect all stars forming the EBG layer.

Brief Description of the Drawing

15 In the Drawing:

Fig 1 is a typical configuration of the prior art where a semiconductor structure is mounted on a substrate using bumps for inter connection means;

20 Fig 2 is a typical configuration of the prior art where a redundant bump is used to minimize the undesired propagation of surface waves along an upper surface of a host substrate ;

Fig 3 is a typical configuration described in the parent application using EBG
25 layers for minimizing undesired propagation of surface waves, where regular polygons tessellate an upper surface of a substrate located under a semiconductor structure;

Fig 4 is a top view of the interleaving star structure used in this invention;

30 Fig 5 shows the top view of the interleaving of a plurality of stars of the present invention to tessellate an upper surface of a substrate; and

Fig 6 is a cross section of an exemplary configuration of a hybrid of the present invention having EBG stars of Fig 4 and 5 used to tessellate the upper surface of a
35 substrate for minimizing undesired propagation of surface waves.

5 Detailed Description

The present invention describes an apparatus and method for improved cross talk suppression in a hybrid assembly by incorporating a single layer made of electromagnetic band-gap (EBG) stars on a hybrid substrate such as, for example, alumina, 10 LTCC (low temperature co-fired ceramic) as well as HTCC (high temperature co-fired ceramic).

The EBG stars reduce the cross talk induced by undesired surface / waveguide modes at high operating frequencies (10 to 20 Ghz) between input/output and power 15 (or ground) pins on the operation of the hybrid.

Fig 1 is a typical configuration of a hybrid of the prior art where a semiconductor structure 103 is mounted on the upper surface 111 of a host substrate 101 using bumps 105, 107 and 109 for inter-connection means. Substrate 101 has an upper metalization layer deposited on upper surface 111 of substrate 101. Conductive paths 113 and 115 20 are etched from a metalization layer, and interconnect bumps 105, 107 and 109 to their respective signal, ground or power sources. In turn, bumps 105, 107, and 109 form a continuous electrical path with pads (not shown) located on semiconductor structure 103, thus proving a path for conductively transferring the signal, ground or power 25 from pads 105, 107 and 109 to specific locations within semiconductor structure 103. An example of a semiconductor structure is a Monolithic Integrated Circuit, MMIC. The MMIC typically may comprise semiconductors, capacitors and resistors, as is well known in the art.

30 In the configuration of Fig 1, at high frequencies (10 to 20 Ghz), signals propagate along the upper surface 111 of substrate 101. Upper surface 111 forms a waveguide like configuration with semiconductor structure 103. This waveguide like path tends to undesirably propagate high frequency signals from their intended destination. One mechanism for this undesired propagation are surface / waveguide modes 35 along the interface of upper surface 111 of substrate 101 and semiconductor structure 109. For example, a signal meant for bump 105 may also be transmitted via surface / waveguide modes to an unintended point along upper surface 111, such as bump 107.

5 Thus some of the signal present at bump 105 will also undesirably appear at bump 107 causing cross talk, interference thereby degrading hybrid operation. Bump 109 is similarly susceptible to high frequency signals from bump 107.

Fig 2 shows a means of the prior art used to minimize undesired surface (waveguide mode) propagation of signals from bump 105 to bump 107. Here, bump 202 has been introduced between bump 105 and 107 to avoid or minimize undesired propagation of electromagnetic energy via surface / waveguide modes from bump 105 to bump 107. Bump 202 is grounded, and effectively reduces the space between bump 107 and bump 105, thereby attenuating surface / waveguide mode energy that may reach bump 105 from bump 107. The introduction of bump 202, while minimizing unwanted electromagnetic energy transfer from bump 105 to bump 107, forces an increase in the surface area of substrate 101 as well as the physical dimensions of semiconductor structure 103. This increases costs and, because of increased size, further exposes semiconductor structure 103 to the reception of other, interfering electromagnetic energy. Furthermore, bump 202 does little to alleviate cross talk effects to bump 109.

Fig 3 shows an improvement over Fig 2 as described in the parent application. A periodic electromagnetic band-gap, EBG (sometimes referred to as photonic band-gap, PBG), lattice structure made of hexagons (regular polygons) exhibiting stopband and slow wave characteristics tessellates upper surface 111 of substrate 101 between signal bumps such as 105, 107 and 109. The hexagons are at a distance from and electrically separate from signal bumps such as, for example, 105, 107 and 109. EBG lattice structures are used to minimize the propagation of electromagnetic energy using surface / waveguide modes in a specific frequency band of operation.

A plurality of hexagonal elements 301 form single layer EBG lattice structure 303, generally printed on substrate 101. Undesired signals traveling from bump 107 towards bump 105 now encounter the effects of the EBG lattice 303 and are attenuated. The thickness of lattice structure 303, shown as t , is, for example, in the order of 1 to 3 mils, depending on the type of ink used to print the lattice structure 303 onto substrate 101, the frequency band to be attenuated, physical dimensions of the

5 semiconductor structure 103.

Each periodic element, or polygon of EBG layer 303, such as polygon 301 and polygon 305, is connected to ground plane 307 using a via. For example, via 309 connects polygon 311, part of EBG layer 303 to ground plane 307.

10 Unfortunately, a single EBG layer made of regular polygons such as hexagons typically offers limited, sometimes insufficient attenuation of undesired surface waves.

Fig 4 shows the structure of star EBG elements of the present invention used to
15 provide additional attenuation for surface waves using a single EBG layer. Star 400 interleaves with star 402 as well as partially shown star 406. Star 402 also interleaves with partially shown star 404. The stars are interleaved with an interspace I between their respective peripheries.

20 Stars 400, 402, 404 and 406 form a window 418 between their respective peripheries. This window 418 is used to accommodate vias passing through the plane of stars 400, 402, 404 and 406.

Star 402 has a center via 422 traversing the substrate and connecting to ground
25 potential as shown in Fig 6. Similarly, star 400 has a center via 420 traversing the substrate and connecting star 400 to ground potential.

A plurality of stars such as 400 and 402 are made of an electromagnetic band gap material on upper surface 111, the electromagnetic band gap material having
30 slow wave characteristics. The plurality of stars tessellate upper surface 111 between conductive paths.

Each of stars such as 400 and 402 have a center section formed from a regular polygon. The center section has projections extending from the center section. The
35 projections on the center section form a periphery. The periphery of each star engages the periphery of adjacent stars along their respective peripheries. The peripheries of adjacent stars are separated from each other by an interspace I .

5 The polygon, for example a square 408 in Fig 4, is surrounded by projections, such as four smaller squares, 410, 412, 414, and 416. If the dimension of the side of square 408 is S , then the dimension of the side of the smaller squares 410, 412, 414, and 416 is approximately $S/2$. The four smaller squares 410, 412, 414, and 416 are centered with respect to the corners of the large square 408. In a preferred
10 embodiment, the centers of stars tessellating upper surface 111, such as star 400 and star 402, are regularly positioned on an approximate staggered rectangular grid of dimension $5S/4$ by $5S/4$, with a stagger of $S/2$, as detailed in Fig 5.

Interspace I can be accommodated by reducing the side S of the large square
15 408 forming star 400, increasing the distance between the center of stars 400 and 402, or both. Also the size of smaller squares needs to be reduced to allow for interspace I as shown. The width of interspace I is meant to be constant over the peripheries of all stars. I is chosen to be compatible with the operating band of the hybrid, the degree of attenuation desired, and the type of EBG material used. Typically, I will
20 become smaller as the frequency of operation of the hybrid increases.

The tessellation of stars shown in Fig 5 is separated by a distance D from
conductive paths such as conductive path 502 and conductive path 504.

25 For example, in Fig 6, the distance D separates star 400 from the vertical surface of bump 608 and its associated conductive path, not shown. Each of the stars is connected to a conductive via. For example star 400 is connected to via 604, while star 402 is connected to via 606. Each elements of EBG layer 612, formed from stars similar to star 400 and star 402, is connected to groundplane 307 using a typical via
30 610.

Conductive via 604 and 606 are connected to ground potential, ground plane
307. Typically, a plurality of stars interdigitated as shown in Fig 5 tessellate the upper surface of the substrate between conductive paths. The stars are typically
35 positioned below a semiconductor structure, such as MMIC 602, forming an EBG layer 612. Without the presence of stars such as 400 and 402, typically surface modes are present at the substrate interface in the vicinity of MMIC 602. For an alumina

5 substrate for example, the presence of these surface modes (leakage energy) is more pronounced near 19 GHz, and more dominant between the Alumina substrate and flip chip MMIC interface of MMIC 602. The E-field intensity has been found to be strongest directly above and directly inside the Alumina substrate interface.

10 METHOD

The method for manufacturing the hybrid assembly of this invention comprises the steps of:

15 a) forming conductive paths, connected for example to bump 608, for conducting high frequency signals along an upper surface 111 of substrate 101;

b) forming stars, the stars made from an electromagnetic band gap material on said upper surface 111. This forms the EBG layer 612, and stars such as 400 and
20 402. The electromagnetic band gap (EBG) layer 612 has slow wave characteristics in a particular band related to the operating frequency of the hybrid. EBG layer 612 is formed as a lattice for tessellating said upper surface 111;

c) mounting MMIC 602 above EBG layer 612 and connecting MMIC 602 using
25 structures such as bump 608 for input and output signals, power and ground.

A star such as 400 or 402 is formed from a polygonal center section (e.g. a first square 408) with projections extending from it. This first square has four equal first sides, each of the four first sides meeting at a ninety degree angle with the the next
30 first side to form first four corners, each of the four first sides having a first length S .

The projections extending from said center section are four second squares, 410, 412, 414 and 416. Each of said second squares have four second sides, each of said second sides one half of said first length, $S/2$. Each of said second sides meet at a
35 ninety degree angle with the next second side to form four second corners. The four second squares are centered on the first four corners of first square 408.

5 The first length chosen for the dimension of the first square is inversely proportional to the operating frequency of said hybrid. Similarly, the interspace *I* between stars along the periphery is inversely proportional to the operating frequency of the hybrid.

10 The semiconductor structures (MMIC 602) are typically mounted over, or in near vertical proximity, to the stars. The semiconductor structures have a plurality of electrical contacts with said conductive paths.

15 Vias, such as via 604 and via 606, connect stars such as 400 and 402 respectively to a ground potential. Typically, the vias traverse substrate 101 and connect to a conductive layer, ground plane 307 on the lower surface of substrate 101.

20 Conveniently, the intersection of four stars forms a window 418 between the four intersecting stars, providing a location for vertical structures, such as bump 608 to pass without electrically connecting to EBG layer 612, or stars such as 400 and 402 part of EBG layer 612.

 All references cited in this document are incorporated herein in their entirety by reference.

25 Although presented in exemplary fashion employing specific embodiments, the disclosed structures are not intended to be so limited. For example, although polygon examples are squares, other polygons, such as triangles can be used to form stars for periodic lattices for tessellating substrate surface 111.

30 Those skilled in the art will also appreciate that numerous changes and modifications could be made to the embodiment described herein without departing in any way from the invention.